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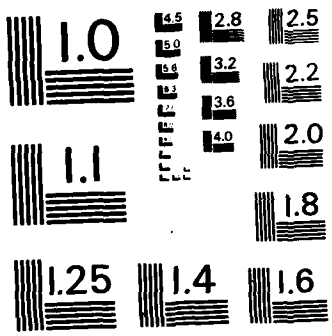

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USE OF HELICOPTERS TO DEVELOP OPERATIONAL CONCEPTS FOR V/STOL AIRCRAFT IN NAVAL MISSIONS

by

Peter S. Montana

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AVIATION AND SURFACE EFFECTS DEPARTMENT

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Vertical and short takeoff and landing (V/STOL) aircraft promise new operational capabilities for the Navy. In the past, new vehicle types have been slow in gaining acceptance because of the difficulty in visualizing how these new vehicles should be employed. Once built, experience gained with the vehicle evolved into an operational concept exploiting its best qualities. Now, competition for fiscal resources has reached a level from

which it may be difficult to justify the development of any new vehicle without having a well-defined operational concept in hand. This report discusses the use of existing large helicopters to develop operational concepts for V/STOL in naval applications.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Vertical and short takeoff and landing (V/STOL) aircraft promise new operational capabilities for the Navy. In the past, new vehicle types have been slow in gaining acceptance because of the difficulty in visualizing how these new vehicles should be employed. Once built, experience gained with the vehicle evolved into an operational concept exploiting its best qualities. Now, competition for fiscal resources has reached a level from which it may be difficult to justify the development of any new vehicle without having a well-defined operational concept in hand. This report discusses the use of existing large helicopters to develop operational concepts for V/STOL in naval applications.

ADMINISTRATIVE INFORMATION

This report is an adaptation of a paper written to satisfy the requirements for the Naval War College Off-Campus Seminar Course "Employment of Naval Forces." The opinions expressed are solely those of the author and do not in any way represent the official position of the David Taylor Naval Ship Research and Development Center or of the Department of the Navy.

INTRODUCTION

The Navy has devoted considerable resources to the development of vertical and short takeoff and landing (V/STOL) aircraft. The state of the art in V/STOL technology has reached a level from which viable V/STOL aircraft can be developed for some Navy missions. VADM Ernest R. Seymour[1] observes that "new vehicle types typically must prove themselves before being built in large numbers for combat..." For example, he states that "early helicopters and the HARRIER VSTOL were considered marginally useful, but over the years have developed into clearly useful weapons." The V/STOL concepts are at a stage where their cost-to benefit characteristics are being carefully evaluated and weighed against other funding priorities of the Navy.

Perhaps a "basic reason that VSTOL programs have proceeded more slowly than originally expected is that no well-defined operational requirement for a naval VSTOL force has been articulated."[1] This is a "Catch-22" type situation. Because V/STOLs have some unique operational characteristics, it is difficult to visualize all aspects of their potential operational applications. On the other hand, without a specific operational requirement, V/STOLs may never be acquired by the Navy.

The best approach would be to operate a V/STOL aircraft to assess the merits of further development of V/STOLs for naval missions. Properties of the simulated V/STOLs should encompass as much as possible those critical flight performance characteristics setting V/STOLs apart from helicopters—speed, payload, range, and altitude—and from fixed-wing aircraft—V/STOL and hover capability.

The use of helicopters to develop operational concepts for V/STOL aircraft is presented in this report. The AV-8A HARRIER aircraft is not a suitable vehicle for simulating a wide variety of V/STOLs because its configuration is too restrictive to be easily modified to accomplish the many missions envisioned for V/STOL. Helicopters, therefore, are the logical choice to simulate V/STOLs, because they may be flexibly configured and already meet the critical vertical flight requirements.

The other flight characteristics (speed, payload, range, and altitude) and their impact on mission performance are topics of discussion presented in this report in the sections on Background and Helicopter performance. Under Background, some historical and technical attributes of helicopters are discussed. The section on Helicopter Performance addresses the current technology of Navy/Marine helicopters and compares their present performance as well as their performance potential with that of fixed-wing aircraft.

BACKGROUND

Perhaps one of the earliest depictions of a helicopter concept was the "Aerial Screw" of Leonardo da Vinci. Considerable progress has been made in helicopter design technology since that time. Rather than develop the history of the helicopter by marching forward in time from da Vinci to the present, the evolutionary aspects will be disregarded in favor of discussing current helicopter characteristics and of briefly establishing the helicopter's place in the broader category of V/STOL aircraft.

There are many definitions of what constitutes a helicopter. Webster's New World Dictionary describes a helicopter as "a kind of aircraft lifted and moved by a large propeller mounted horizontally above the fuselage: it differs from the autogiro and gyroplane in that this propeller is turned by motor power, and there is no auxiliary vertical propeller for forward motion." Schneider[2] offers a comprehensive glossary of terms relating to types of V/STOL aircraft from which the following are taken:

Helicopter	•	An aircraft whose vertical lift and propulsive thrust is provided by the same rotor(s).
Compound Helicopter	•	A helicopter derivative wherein lift and[or] thrust in the high-speed mode is provided by other systems such as wings, propellers, turbojets, etc.
Convertiplane	•	A term for aircraft capable of converting from helicopter-type flight to high-speed airplane-type flight.

From these definitions and from others in the same reference, it is evident that there is an orderly progression from vehicles capable of vertical flight to vehicles capable of horizontal flight. Although it is not obvious, all of these vehicles are subject to the same laws of physics. Similar aerodynamic phenomena can occur on different types of vehicles traveling at widely varying speeds, and result in different constraints on the performance of the respective vehicle concepts. For example, the tip of a rotor blade on a helicopter flying at 150 knots has about the same airspeed as the wing of a fixed-wing aircraft flying at 600 knots. In this case, 600 knots represents flight at the speed of sound for fixed-wing aircraft and 150 knots represents the speed at which the tip of the advancing blade of a helicopter experiences flow at sonic velocity. Because the same laws of physics apply, different vehicle concepts have different performance limitations. It becomes a design decision to select those attributes in a vehicle which are most important in accomplishing a specific mission. Perhaps, for example, having small aircraft is more important than having long range. Or, more germane to this discussion, good hover capability might be more important than good forward flight capability. These types of tradeoffs are difficult to make and may be mutually exclusive.

To illustrate further, the one attribute of the helicopter which sets it apart from other types of aircraft is the capability to hover efficiently. This attribute, illustrated by Siewert[3] in Figure 1, means that helicopter rotors can generate more thrust per horsepower than other types of vertical lift systems. As a result, direct lift V/STOLs (turbofan/turbojet) require as much as eight times

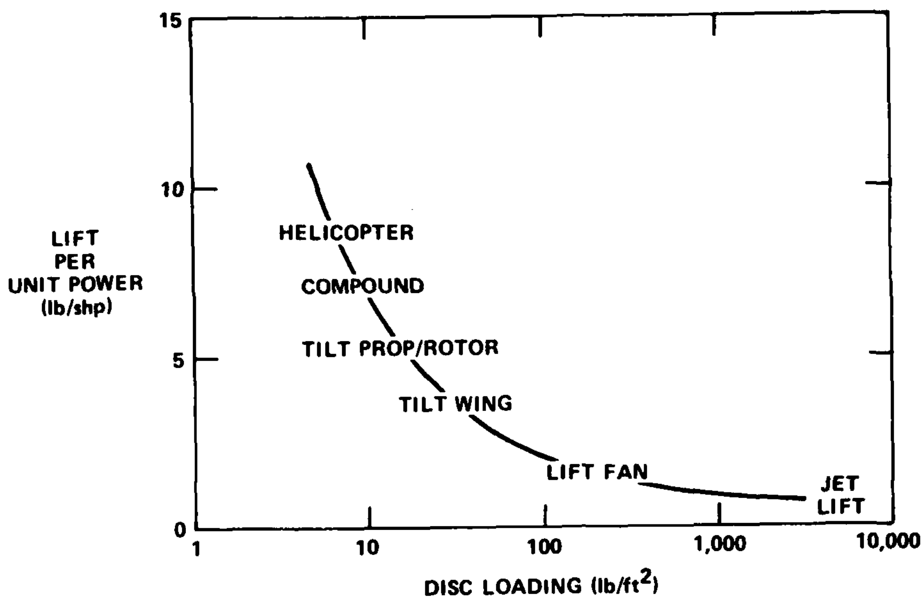

Figure 1 - Lift System Efficiency
(From Reference 3)

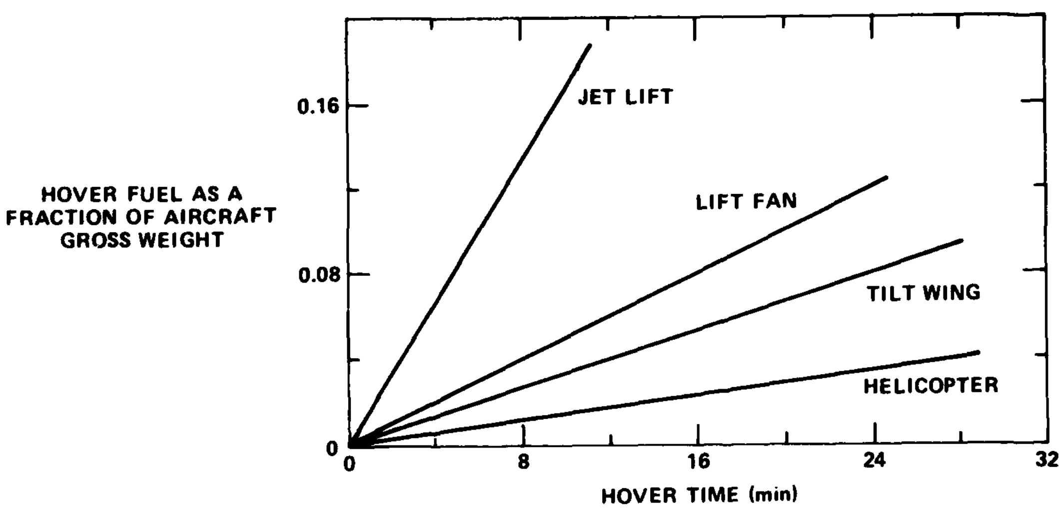

Figure 2 - Fuel Required to Hover
(From Reference 3)

the fuel per minute at hover than do helicopters. This characteristic (Figure 2) has a direct adverse impact on V/STOL design through fuel requirements.

The laws of physics impose an absolute upper limit on hovering efficiency for any given disc loading. Thus, advances in technology (as long as only aerodynamic devices are considered) will not alter the relative hover efficiencies of devices with different disc loading; technology can only improve hover efficiency up to the maximum attainable value for a given disc loading. Hence, if a mission calls for a considerable amount of hover time, a helicopter would be a better choice than a jet lift aircraft. This trend in hover time available is illustrated by Schneider[2] in Figure 3. As changes are made to the basic helicopter such as thrust compounding (Sikorsky ABC) or converting to fixed-wing (Bell Tilt Rotor), hover time decreases by design because fuel consumption increases.

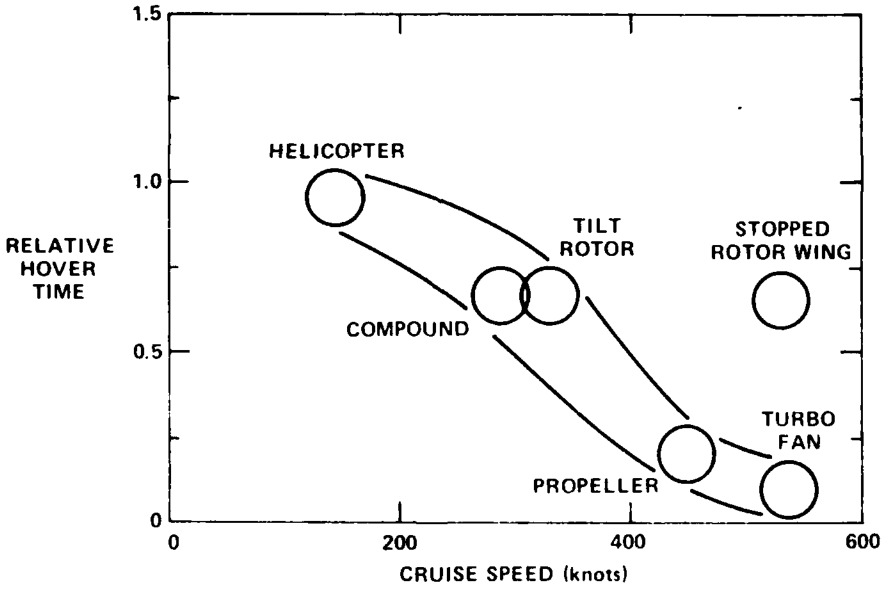

Figure 3 - Relative Hover Time

Hover efficiency and relative hover time are abstract concepts when taken out of the context of actual vehicles. Disc loading, hover efficiency, and maximum level-flight speed for some current Navy helicopters are shown in Table 1. The values are consistent with those values presented in Figures 1 and 3.

TABLE 1 - NAVY HELICOPTER HOVER EFFICIENCY PARAMETERS

Helicopter	Disc Loading (lb/ft^2)	Hover Efficiency (lb/shp)	Maximum Speed (knots)
SH-2F	8.4	4.7	150
SH-3H	7.0	7.5	137
SH-60B	9.7	6.5	160
RH-53D	10.2	5.4	176
CH-53E	15.0	5.6	170

A review of the maximum speed capability of helicopters was made using Janes[4] as a source for data. Results of this review are shown in Figure 4. Pure helicopters appear to have a maximum speed potential of about 180 knots. This is not a revelation to helicopter technologists, but only an indication of the aerodynamic facts of life governing pure helicopters. This speed limitation results from the development of a reverse velocity region on the rotor. This region is present on all helicopters in forward flight, and its size is governed by the ratio of forward speed to rotor tip speed. The reverse velocity region encompasses about 40 percent of the inboard blade radius on one side of the helicopter at 180 knots. When a section of a blade is in the reverse velocity region, the capability to provide thrust is severely reduced and helicopter control and vibration characteristics are adversely affected. Some advanced rotor concepts being developed promise increased maximum speed capability—concepts such as the reverse velocity rotor and the reverse blowing circulation control rotor. However, the most emphasis appears to be on making order-of-magnitude increases in performance which can be attained with concepts such as the X-Wing, Tilt Rotor, and ABC* for rotary wing aircraft and with other forms of V/STOL aircraft.

*A Sikorsky Aircraft helicopter with two counter-rotating coaxial rotors optionally incorporating auxilliary propulsion.

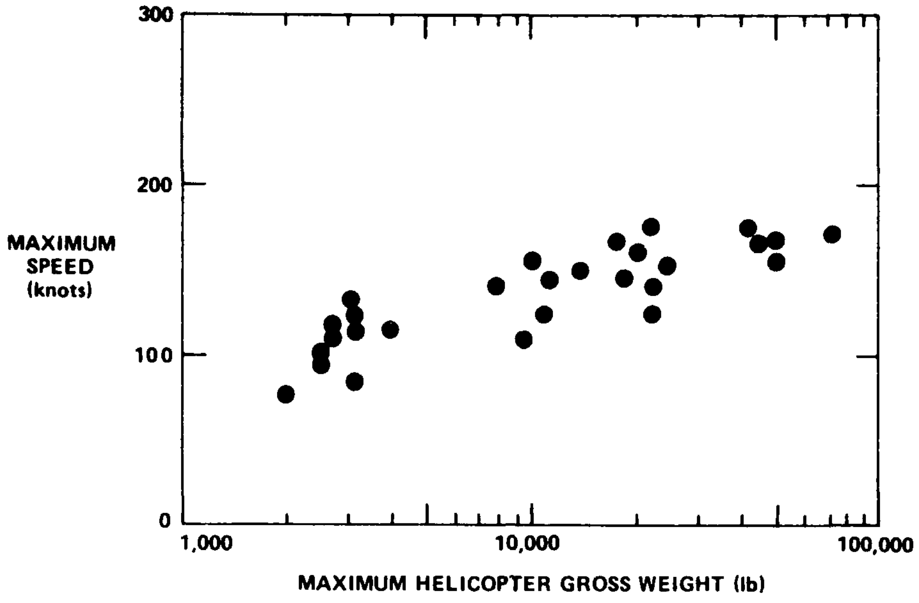

Figure 4 - Helicopter Maximum Speed Capability

Less obvious advances have been made in the last ten years which are not reflected in the gross performance parameters of range, speed, and endurance. These important areas include ride quality, stability and control, reliability and maintainability, and pilot work load reductions, which have a major impact on mission performance. One example is higher harmonic control[5] which is capable of reducing helicopter rotor induced vibrations by 90 percent. The effect of this vibration reduction should be evident in improved reliability of all fuselage equipment, especially avionics, and in greatly reduced crew fatigue, making longer missions more feasible.

HELICOPTER PERFORMANCE

Since the late 1960's and early 1970's, there has been a large investment in the development of V/STOL aircraft with an emphasis on concepts promising fixed-wing-type performance. In the same period, relatively few "new" helicopters were developed for military applications other than the Sikorsky UH/SH-60 and AH-64. Most helicopter developments were upgrades or modifications of previous helicopter designs: SH-3A to SH-3H; UH-1 to AH-1; and an extreme case, CH-53A to CH-53E.

Considering the delays and cost increases in V/STOL programs, not to mention an outright failure or two, helicopters should be re-evaluated to assess their performance potential for a range of missions envisioned for V/STOL aircraft. With appropriate mission performance, helicopters could provide a low-risk means of developing V/STOL operational concepts.

Initially, plans for V/STOL aircraft were very ambitious, encompassing nearly all of the missions for fixed-wing aircraft and helicopters. However, only two missions have been selected for discussion—anti-submarine warfare (ASW) and airborne early warning (AEW). Mission performance is addressed by comparing the flight capabilities of helicopters and fixed-wing aircraft.

Many Navy helicopters were designed, or have evolved, to the light airborne multi-purpose system (LAMPS) mission. The LAMPS mission is primarily a combination of ASW and ASMD (anti-ship missile defense) with secondary roles including SAR (search and rescue), logistics support, VERTREP (vertical replenishment), reconnaissance, plane guard, and tactical air control. The helicopters currently performing the LAMPS mission are the SH-2F and the SH-3H. (Although the SH-3H is not normally referred to as a LAMPS helicopter because of size, it performs essentially the same mission as a LAMPS helicopter from its base on aircraft carriers.) The SH-60B is about to enter the inventory as the LAMPS helicopter of the future. All of these helicopters were constrained in size due to the requirement to operate from small ships. As a result, helicopter mission performance capabilities are limited, as shown in Table 2.*

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*Data for the aircraft characteristics presented throughout this report are from various sources including: (a) "Jane's All the World's Aircraft," editions "1972-1973," "1973-1974," and "1982-1983," Jane's Publishing Co., New York; and (b) reports of higher classification.

TABLE 2 - LAMPS ASW MISSION PERFORMANCE[10]
(Mission 1 hr on station at mission radius)

Helicopter	Max Weight (lb)	Rotor Diameter (ft)	Mission Radius (nm)	Ferry Range (nm)
SH-2F	12,000	44	35	300
SH-3H	21,000	62	160	640
SH-60B	21,884	54	150	540

The Navy and the Marine Corps operate other helicopters which are not subject to the same size constraints as are the LAMPS-type helicopters. These helicopters—the RH-53D, CH-53E, and the future MH-53E—have been designed to operate from larger flight decks in logistics or mine countermeasure missions, but could be adapted to perform other missions such as ASW and AEW. To this end, the estimated ASW mission performance for the large Navy and Marine Corps helicopters is presented in Table 3 along with data for the S-3A fixed-wing ASW aircraft. The ASW mission is 1 hour on station at mission radius. Performance is based on maximum internal fuel plus external fuel tanks, if appropriate to the aircraft.

TABLE 3 - ESTIMATED LARGE HELICOPTER ASW MISSION PERFORMANCE

Helicopter	Max Weight (lb)	Rotor Diameter (ft)	Mission Radius (nm)	Ferry Range (nm)
RH-53D	42,000	72	240	830
CH-53E	69,750*	79	240	940**
MH-53E	69,750*	79	340	840
S-3A***	42,500	69 (wing span)	1,140†	3,000+

*Maximum weight with internal cargo; for external cargo, maximum weight is 73,500 lb.

**Extra fuel cells mounted in cargo area.

***Fixed wing carrier-based ASW aircraft.

†Normal mission limited to 5.5 hr (about 800 nm) by crew endurance.

The weights listed in Table 3 are the maximum allowable gross weights for each helicopter and are not projected ASW mission takeoff weights. For example, the MH-53E helicopter has an empty weight of 36,336 pounds and a fuel capacity of 23,362 pounds for a combined weight of 59,698 pounds. Thus, there is a potential of about 10,000 pounds for an ASW-related payload. Since the zero fuel weight* of the SH-60B with full ASW payload is about 17,800 pounds, the MH-53E has more than adequate payload capability to carry the same ASW mission equipment as the SH-60B while providing more than twice the combat radius.

As a more absolute measure of effectiveness, helicopter performance may be compared with the S-3A fixed-wing ASW aircraft. With the possible exception of the land-based P-3C aircraft, the S-3A probably has the best ASW mission capability of any aircraft in the world. The S-3A has about three times the mission radius as the proposed MH-53E ASW helicopter and about seven times that of the SH-60B LAMPS helicopter. The MH-53E with its extra load capacity can probably accommodate the same weapon and sonobuoy load as the S-3A; however, the SH-60B has only about one-half the load capability of the S-3A. This, along with the data in Tables 2 and 3, indicates that the S-3A has much more ASW mission capability than do most helicopters. In addition, current technology helicopters can provide substantial increases in ASW mission capability over the LAMPS helicopters, if helicopter size constraints are relaxed to permit use of "existing" large helicopters.

The standard AEW (airborne early warning) mission for the Navy's E-2C fixed-wing aircraft is conducted at a radius of 200 nautical miles at various altitudes and flight conditions. The current LAMPS helicopters are able to conduct similar searches using on-board equipment, but are unable to match the mission radius of the E-2C, as shown in Table 2. The estimated time on station (TOS) at 200 nautical miles for large helicopters is almost comparable to that of the E-2C; see Table 4.

*Zero fuel weight includes complete weight of helicopter (i.e., fuselage, engines, rotors, crew, mission equipment, weapons, etc.).

TABLE 4 - ASW MISSION CAPABILITIES
(Loiter mission at 200 nautical miles radius)

Helicopter	Max Weight (lb)	Rotor Diameter (ft)	TOS (hr)	Altitude (ft)
RH-53D	42,000	72	2	<15,000
CH-53E	69,750	79	2	<15,000
MH-53E	69,750	79	4	<15,000
E-2C*	51,600	81 (wing span)	2.4-3.6	S.L.-35,000

*Fixed Wing carrier-based AEW aircraft.

A major drawback in using helicopters for the AEW mission is their limited altitude capability which impacts radar performance as reduced radar horizon (line of sight) and reduced detection range against high altitude targets due to atmospheric refraction. The effect of refraction is difficult to quantify without considering the details of radar systems and theory. Qualitatively speaking, below about 25,000 feet in altitude, radar waves are refracted by the atmosphere and bent toward the earth's surface. This makes it difficult to acquire high altitude targets at long range. For radar horizon, simple calculations give reasonable ratios for the effect of platform height. For instance, doubling altitude increases horizon range by about 40 percent, tripling by about 75 percent, and quadrupling the altitude increases the range by about 100 percent. Since line of sight to the horizon from a 10,000-foot altitude is about 100 miles, the capability to cruise at 30,000 feet could provide a large radar range increase against surface or low flying targets. The reduced radar range for AEW helicopters due to altitude limitations must be balanced against other considerations affecting their employment.

Two other factors worth noting are spotting factor and helicopter in-flight refueling (HIFR). Spotting factor is a measure of the amount of deck space required for an aircraft. It is empirically determined by using detailed deck and aircraft models to find the number of aircraft capable of being "spotted" on a flight deck. The spotting factor is the ratio of the spotting number of the subject aircraft to a reference aircraft's spotting number (the current reference is the A-7 aircraft). Table 5 lists spotting factors for the aircraft presented in this report.

TABLE 5 - AIRCRAFT SPOTTING FACTORS

Aircraft	Factor	Aircraft	Factor
SH-2F	0.47*	CH-53E	1.59
SH-3H	0.79	MH-53E	1.50
SH-60B	0.52*	S-3A	1.49
RH-53D	1.46	E-2C	1.97

*Estimated

The large helicopters have about the same spotting factor as the S-3A, and hence could be traded one for one on the basis of space considerations. In addition, these helicopters have about 75 percent of the spotting factor of the E-2C and could be traded on a four helicopter to three E-2C aircraft ratio.

Helicopter in-flight refueling refers to the capability of helicopters to refuel from a ship without landing. This task is accomplished by hovering over or along side a ship and taking aboard a fuel line from the ship. Many Navy ships are equipped for HIFR and could provide fuel to extend a helicopter ASW or AEW mission TOS/range if necessary in some tactical situations (for example, dispersed formations).

Significant improvements to mission radius for ASW, and radius and time-on-station for AEW can be obtained (over LAMPS helicopters) by relaxing size constraints. At the same time, fixed-wing aircraft still have superior performance in ASW due to greater range and in AEW due to greater altitude capability. The capability of future V/STOL aircraft will be in between the performance characteristics of the large helicopter and the fixed-wing aircraft.

DISCUSSION

The future of V/STOL aircraft in naval applications will be determined by the development of operational requirements fully suited to the unique characteristics of the V/STOL concepts. Certain missions, such as those proposed for the JVX aircraft, are easy to postulate because they fall in a regime not amenable to fixed-wing aircraft. In this context, the JVX is viewed as a replacement for helicopters dedicated to the vertical assault mission—the CH-46 and the CH-53.

The JVX also does not require the construction of new ships, but uses the existing amphibious force ships already committed to the Marine Corps.

When V/STOLs are considered for missions traditionally performed by fixed-wing aircraft, the situation is much different. The performance of V/STOL aircraft is limited by the laws of physics and often by the need for multiple lift systems or other heavy mechanical equipment not needed by conventional takeoff and landing (CTOL) fixed-wing aircraft. The result is that V/STOL performance will always be less than CTOL performance if traditional measures of comparison, such as range and payload, are used. However, unique capabilities of V/STOLs offer opportunities for new missions and/or operating concepts which may be of great value to the Navy. To take fullest advantage of V/STOL capabilities, new ships should be built. Such a commitment in light of overall funding constraints would result in reduced construction of ships of proven worth such as aircraft carriers. Thus, using V/STOLs in the vertical assault mission is a low-risk effort in comparison to the very high risks of building new V/STOL carriers and giving up some conventional aircraft carriers.

A means of developing V/STOL operating concepts for fixed-wing missions with reduced risks is needed. One approach is to wait until the JVX is built—assuming it is built—and then use the JVX to develop operating concepts. This conservative approach does not take advantage of current technology, and thus may delay V/STOLs from entering the fleet in new roles until well after the turn of the century.

An alternative approach is to use current-technology, large helicopters to develop operating concepts for V/STOLs. As stated, large helicopters offer a significant improvement over the LAMPS-type helicopters in ASW and AEW missions; however, large helicopters can operate only from a limited number of ships,[6] other than aircraft carriers (CV), most of which are in the amphibious force.

The amphibious assault ship (LPH) could be used as the demonstration platform for the V/STOL concept of operations. The advantage in using an LPH is its configuration as a small aircraft carrier. The LPH is equipped to operate and support helicopters (including the RH-53D, CH-53E and MH-53E) for extended periods. With minor modifications, the LPH could support specialized equipment for ASW and AEW missions while continuing to offer more than adequate stowage for weapons, stores, and fuel.

The LPH-2-class ships are nearing the end of their useful life; however, there are plans to extend their service until newer ships (LHD) are available as replacements. Configuring an LPH as an ASW/AEW ship would provide a low-risk, low-cost opportunity to investigate the merits of V/STOL in ASW and AEW missions without seriously impacting the amphibious force capability or draining resources from carrier battle groups (CVBGs). The larger helicopters, even when configured for ASW or AEW, would still have secondary logistics support, vertical assault, or mine countermeasures mission capabilities. Thus, a reconfigured LPH could supplement helicopters operating in these primary missions from other amphibious force ships.

Applications of an LPH configured for ASW/AEW missions outside the amphibious force could include: sector ASW/AEW in a CVBG, surface action group support, convoy escort, and independent area ASW missions. All of these missions are presently envisioned for future V/STOL ships.

The cost and risks involved in developing V/STOLs are high; therefore, without some means of proving operational concepts in advance, V/STOLs may not survive cost-benefit analyses when competing with fixed-wing systems. Large helicopters can provide the means to transition gracefully to V/STOL operations at much lower cost and risks. Large helicopters are available now and can simulate V/STOLs until such time as the technology is mature enough for V/STOL development.

The future of helicopters in naval applications still lies in their capability to perform missions that require small decks and/or long hover time. Helicopters and V/STOLs are all part of the same class of vehicles with performance distinctions dependent only on the degree of optimization for hover or for forward flight. Every effort should be made to take advantage of existing technology in helicopters to develop the operational concepts for advanced technology V/STOL aircraft which will extend the Navy's operational flexibility in the future.

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